D
1
357
314

United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

Research Paper **NC-314**

Allometric Biomass Estimators for Aspen-Dominated Ecosystems In The Upper Great Lakes

Donald A. Perala and David H. Alban

The United States Department of Agriculture (USDA) prohibits discrimination in its programs on the basis of race, color, national origin, sex, religion, age, disability, political beliefs and marital or familial status. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (braille, large print, audiotape, etc.) should contact the USDA Office of Communication at (202) 720-5881 (voice) or (202) 720-7808 (TDD).

To file a complaint, write the Secretary of Agriculture, U.S. Department of Agriculture, Washington, D.C. 20250, or call (202) 720-7327 (voice) or (202) 720-1127 (TDD). USDA is an equal employment opportunity employer.

Printed on recycled and recyclable paper.

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication December 21, 1993
1994

Allometric Biomass Estimators for Aspen-Dominated Ecosystems in the Upper Great Lakes

Donald A. Perala and David H. Alban

Alban *et al.* (1991) recently described the climate, geology, soils, and the biotic structure and dynamics of four contrasting ecosystems dominated by quaking and bigtooth aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.). Other papers describe how those ecosystems responded to perturbation (Alban and Perala 1990a, 1990b, 1992; Perala 1985, 1987; Perala and Alm 1989). Common to most of those papers were biomass estimates for the tree and shrub layers. In this paper, we document the equations we used to develop those estimates. We derived the estimators from weight and dimensional analysis of a subsample of stems measured on sample plots. To broaden the analysis, we also included tree data from four other sites (tables 1 and 2). We found much variability among sites that could not be adequately explained by stand or soils data. Nevertheless, these equations should be useful in estimating woody plant components of similar forests on upland soils in the Upper Great Lakes region.

METHODS

The main study sites (Alban *et al.* 1991) ranged from 8 to 20 ha. Each area, except for Happy Hollow, was divided into 1-ha plots that were harvested and regenerated, or left as uncut controls (Alban and Perala 1990a, 1990b). Harvesting was at two intensities: whole-tree clearcut and merchantable bole clearcut. Shelterwood cuts were also installed at Cloquet (Perala and Alm 1989) and at Pike Bay. Four of the clearcut plots were converted to *Picea glauca* (Moench) Voss at each treated site (Perala 1985, 1987).

Donald A. Perala is a Research Forester and **David H. Alban** is a Research Soil Scientist with the North Central Forest Experiment Station, Grand Rapids, MN.

We stratified the woody vegetation into two layers rather than vegetational class: the *tree* layer, and the *shrub* layer. The tree layer included all trees and shrubs >2.5 cm d.b.h. Before harvesting, we measured these stems to the nearest mm with metal tape at 1.37 m height on 0.05-ha circular measurement plots (Alban and Perala 1990a, 1990b). We felled a subsample of 5 to 20 of these trees per species per site, removed the limbs, and sectioned the boles into 1-m bolts. Bolts and limbs were weighed in the field. Disks 25-30 mm thick were sawn from the bottom of each bolt; these and limb subsamples were sealed in plastic bags and taken to the laboratory where they were processed as bole wood, bole bark, foliage, live limbs, and dead limbs. Diameter of each fresh tree disk was measured at right angles through the pith; the inside bark volume of the bolts was determined by Smalian's formula (Wenger 1984); and bolt volumes were summed to get tree volume.

Miles (1979) excavated the root systems of five aspen trees from Cloquet. We excavated three aspens and nine conifers from a previous study site at Pike Bay (Perala and Alban 1982). These systems, roots >5 mm diameter and including 15-cm stump, were weighed fresh and subsampled for laboratory determinations.

Before and after harvesting, we sampled shrubs and tree seedlings on 4-m^2 plots (Alban and Perala 1990a, 1990b). This shrub layer (woody plants >15 cm tall but <2.5 cm d.b.h.) was recorded by species and by caliper class (1-3 mm, 3-5 mm, ..., 23-25 mm) determined at 15-cm height with a notched gauge. Stems >25 mm caliper but less than 2.5 cm d.b.h., were measured to the nearest mm at 15 cm with a steel diameter tape. We collected up to 30 sample shrubs per species per site per sample year representing the range of sizes encountered. In the laboratory, shrubs were separated into leaf and perennial tissues, *i.e.*, wood and bark of stem and limbs.

Shrub-layer roots 5+ mm caliper (determined with the same notched gauge as above) were collected before harvest but not after. The roots were wrenched out of the ground by pulling forcefully on the stem while trimming away roots <5 mm. Larger roots that broke were excavated by trowel to the 5-mm threshold caliper. Most roots were shallow, just under the forest floor, and were extracted rather easily. Shared roots (*Populus*) or underground stems (*Corylus*) of clonal species were apportioned at the midpoint between connected stems. The root sample contained little "stump"; the stem was severed as close as practical to the root crown.

As early as 5 years post-harvest, tree seedlings, especially aspen suckers, began to surpass the minimum 2.5-cm-d.b.h. threshold into sapling size. They were then measured at 1.37-m height. Saplings representing this emerging tree population were felled near the groundline and weighed and subsampled similar to mature trees, except the laboratory determined component weights were limited to total bole (bark not separated), limbs (live and dead), and foliage. The regressions we report here for saplings are for stems (bole+limbs) and foliage only.

All vegetation samples were oven dried (75°C), weighed, and prepared for chemical analyses (Perala and Alban, in prep.). Wood specific gravity (ovendry weight/fresh volume, g/cc), was calculated for tree boles. All calculations were corrected for chain saw kerf. We pooled all these tree sample data along with tree data from four other sites (Verry 1969, Alban 1985) collected in the same way.

We developed tree component biomass estimators built upon the allometric model

$$W = a*D^b*H^c \qquad [1]$$

fit to the tree sample data, where W is component ovendry weight, kg; D is d.b.h., cm; and H is height, m. A second model,

$$W = a*D^b*A^c \qquad [2]$$

where W is component ovendry weight, g, and A is age, years, was fit to data for shrubs (D=mm at 15-cm height) and saplings (D=mm at 1.37-m height). A third model

$$H = a*D^b \qquad [3]$$

to estimate tree height when only d.b.h. is known, was fit to the tree mensurational data.

We explored the need for site-specific models by introducing dummy variables (Weisberg 1985) to test soil, treatment, and other effects on the a-parameter (*e.g.* Buech and Rugg 1989). Soils ONTONAGON, WARBA, ZIMMERMAN (includes Redby and Leafriver at Happy Hollow unless otherwise specified), GRAYCALM, REDBY, KALKASKA, and GRAFTON were contrasted with Cloquet; logging method FULL was contrasted with tree length; and regeneration options convert to SPRUCE (Perala 1985) and SHELTerwood for paper birch at Cloquet (Perala and Alm 1989) or hardwoods and conifers at Pike Bay, both with or without GLYphosate, were contrasted with natural aspen coppice. In [2], we assumed shrubs before harvest were 1 year old for computational convenience ($1^c=1$) because we did not know how old they were. We assigned them a dummy variable, OLD, to test for significant differences from newly regenerated shrubs and trees.

Some species had few sapling- or shrub-size data. These data were pooled and analyzed with a dummy variable, SHRUB, in the model to account for measurement height. Still, some species had so few observations that the data were aggregated and analyzed by genus or family. Finally, we aggregated for analysis all aerial component data by trees, saplings, and shrub layer. For trees and saplings, we included a variable, SG, for the published specific gravity of the wood component by species.

Root data were meager for most woody species. Rather than attempt to fit independent regressions by species, we pooled the tree root data into a common set and fit it to [1]. The shrub layer root data were pooled and fit to [2], and the residuals were averaged by species to create a new variable, SP. This term estimates the maximum possible reduction in sum-squares attributable to species, assuming no species effect on the

diameter parameter. Of course, the SP parameter is 1.000 in this pooled equation, and the value of SP was simply multiplied with the overall constant to obtain species constant.

No root data were available for saplings; however, we assumed that roots should be proportional to leaf mass (to conduct water and solutes) and to stem mass (for structural support). We fit the shrub-layer data to the model

$$RW=a*SW\text{^}b*LW\text{^}c \quad [4]$$

to derive an estimator for root mass of saplings, where RW is root ovendry weight, SW is stem ovendry weight, and LW is foliage ovendry weight.

For efficient analysis of the pooled data sets, to linearize relationships, and to stabilize variance, Eqs. [1]-[4], with their attendant site- and treatment-specific (and species-specific in generic equations) variables were fit by linear regression of the log-transformed equivalents,

$$\ln(W) = \ln(a)+b*\ln(D)+c*\ln(H)+\ln(p_i)*Z+d*\ln(SG)+\ln(e) \quad [5]$$

$$\ln(W) = \ln(a)+b*\ln(D)+c*\ln(A)+\ln(p_i)*Z+d*\ln(SG)+\ln(e) \quad [6]$$

$$\ln(H) = \ln(a)+b*\ln(D)+\ln(p_i)*Z+\ln(e) \quad [7]$$

and

$$\ln(RW) = \ln(a)+b*\ln(SW)+c*\ln(LW)+\ln(e) \quad [8]$$

where p_i is the estimated parameter for the $_i$th dummy variable Z having values of 0 or 1 (Weisberg 1985), and e is an error term, normally distributed with a mean of 0.

The best subsets method (Weisberg 1985) was used to define significant variables in the regressions. This method is liberal and sometimes retained variables having probabilities in excess of 0.10. We accepted them, however, because our objective was to favor soil- and treatment-specific equations. The bias inherent in logarithmic estimators was relieved with the approximate method of Baskerville (1972).

We report the results of the analyses in the nonlinear transform of [5], [6], [7], and [8] as

$$W = a*D^b*H^c*p_i^Z*SG^d*e \quad [9]$$

for tree components;

$$W = a*D^b*A^c*p_i^Z*SG^d*e \quad [10]$$

for sapling and shrub components;

$$W = a*D^b*SP*e \quad [11]$$

for shrub roots; and

$$W = a*SW^b*LW^c*e \quad [12]$$

for sapling roots. We henceforth refer to p_i^Z as **multipliers** having either the value 1 when Z=0, or >1 or <1 when Z=1. Note that e is now the skewed error term with a geometric mean of 1.0, and SG is used only in generic equations.

RESULTS AND DISCUSSION

The regressions produced tree biomass equations that estimated bole wood and bole bark very well (adj R^2>0.98), roots and stump surprisingly well (R^2=0.93), live limbs (R^2=0.87-0.96) and leaves (R^2=0.22-0.96) less precisely, and dead limbs (R^2=0.26-0.91) worst of all (table 3). D.b.h. was the strongest predictor variable and was retained in all equations. Of the 15 largest species data sets, height was significant in 13 of the bole wood equations, in 11 bole bark and 10 live limb equations, but in only 5 dead limb and 4 leaf equations. Despite p<0.072, we retained height in the root+stump biomass equation because it helped minimize the residual mean square.

By inspecting the values of the soil multipliers where Cloquet=1.0 (table 3), we can appreciate how much variability exists by tree component among the soils in this study. For a tree of a given d.b.h. and height, predicted weight of dead limbs ranges more than thirtyfold across all species and soils:

Component	Relative range
dead limbs	30.8
leaves	5.8
live limbs	2.4
bole bark	2.1
bole wood	1.4

For a tree of given diameter and height, predicted dead limb weight for *Abies balsamea* varied sixfold, the widest component range among soils for a single species.

Among the single species equations, bole bark multipliers are smallest on the Cloquet and Grafton sandy soils. These are the poorest sites (table 1) so the effect is plausible. Multipliers for dead limbs are larger than 1.0 except on Graycalm, Redby, and Grafton soils, where they tend to be less. Although this is a rough trend with site index, limb persistence is a genetic trait modified by stand density and composition during development. We should not expect persistence trends without first accounting for these factors (we cannot). No other tree component patterns are apparent among single species equations.

Despite the many significant allometric differences among soils, it is imprudent to declare soil character as the cause based on this limited sample having only weak interpretability. We anticipated that multipliers might be greater for leaf mass on productive, moist forest soils able to support more foliar area (Grier and Running 1977). Such response may well be noticeable over a wider range of site quality. But our studied sites are all commercially productive and so do not span the lower range of site quality. Another hindrance is that soils and climate are confounded. Only the Redby soil is replicated, but only weakly, among these study sites traversing the Lake States from near the Minnesota-Canada border to northern lower Michigan. Demonstrating real allometric response to soil character requires considering relative stocking as well. Simply too few sites are studied here to analyze soil character/allometric response amid climatic and stocking gradients.

One factor important to biomass estimation is variability in specific gravity. Our specific gravity estimates are generally higher than published values (table 4), especially for the maples (+21 percent for *A. saccharum*) and for trees from the Ontonagon soil. Published values were determined from small, clear blocks that had been dried to 12-percent moisture content (Bendtsen *et al.* 1987). Our determinations on disks that had any number of knots and other inclusions probably contribute to our overestimates. On the other hand, Smalian's formula that we used overestimates volume (Wenger 1984), and our samples were dried to much less than 12-percent moisture content. Both these factors would lower specific gravity estimates. On balance, our determinations are probably not significantly different from published values that generally have coefficients of variation of 10 percent (Bendtsen *et al.* 1987).

In the generic tree equations (table 3), published specific gravity was a significant variable for estimating bole wood despite many significant dummy variables for species. This reflects how our specific gravity estimates vary among species in departing from published values (table 4). Specific gravity was also significant in estimating bole bark mass. We are unaware of any work relating bark and wood specific gravity, so we cannot say that the relationship is real although it is intuitive. Possibly the relationship of bark mass to specific gravity is an artifact of calculating the latter from bole wood volume and mass, both related strongly to d.b.h. That is, the relationship of bole bark weight to d.b.h. may be significantly non-linear in the log-log mode.

We tested whether sampling date (Julian day) introduced another multiplier for biomass components of *Populus tremuloides*, our most widely distributed data set in both time and space (table 5). The risk of confounding time with space was minimal because all these trees were sampled throughout the summer on each soil, except Graycalm was sampled in the spring before leaf-on and Redby was sampled in early summer. Furthermore, the soil multipliers do not trend with Julian day (table 3). Sampling date introduced multipliers >1 for height, dead limbs, bole bark, and bole wood; and a multiplier <1 for leaves. The latter is understandable because leaves are lost throughout the summer to storms, grazers, disease, and senescence. But multipliers >1 seem indefensible. For example, height growth ceases **before** diameter growth (Fraser 1959) so that the height multiplier should **diminish** as the season progresses. On the other hand, radial shrinkage as soil water is depleted in late summer would tend to explain these anomalies. However, the shrinkage is so slight it can only be detected with careful instrumentation (Fraser 1959). More research is needed to determine whether limbs die throughout the summer faster than they are shed, whether bark is formed later in the season than is wood, and

whether increased bole wood density from late wood formation is detectable with these relatively crude field techniques.

The sapling and shrub regressions produced equations somewhat less precise than the tree equations, but apparently more sensitive to soil and treatment (tables 6, 7, 8). The root regressions were the poorest fitting of the three components estimated for saplings and shrubs. LW (leaf weight) dropped out of the sapling root mass regression, suggesting that water conducting area in roots and stems is similarly proportional to their total respective component mass. The root equations give mass estimates that agree closely with the data of other studies (Perala and Alban 1982, Ruark and Bockheim 1987). Nevertheless, the sapling root mass predictor is unvalidated and the estimates should be considered cautiously.

For species in common, the Ontonagon clay had smaller multipliers than did the Cloquet fine sandy loam for leaf and stem mass. The Warba silt loam also tended to have smaller multipliers for leaf mass but larger multipliers for stem mass. The OLD shrub layer had smaller multipliers for leaf mass compared to newly regenerated shrub layers, whereas these multipliers were greater in the converted and shelterwood stands. These differences probably reflect differences in stem architecture and leaf production in response to competition. The woody regeneration in shelterwoods, and especially in the converted stand, did not suffer from the intense crowding common to young coppice stands or from the multilayered canopy in mature stands. These relatively free-growing individuals had the luxury of capturing solar energy from as much foliage as they could possibly produce. The soil associated differences are harder to rationalize with just three sites. The Cloquet soil is the least productive of the three, has the largest leaf multiplier, yet has a multiplier intermediate for stem mass.

USING THE ESTIMATORS

All equations, whether for shrubs, saplings, or trees, are used in the same manner. To illustrate, suppose we wish to use the generic estimator for foliage weight of red pine trees growing on a Redby soil. The full equation extracted from table 3 (page 21),

```
LEAVES=0.02979*DBH^2.582*HEIGHT^
-0.9130*0.9969^JULIAN*1.004^JULIAN
*0.08923*DBH^0.8835*1.195                [13]
```

contains all relevant terms for red pine foliage. Combining terms gives

```
LEAVES=0.003176*DBH^3.466*HEIGHT^
-0.9130*1.001^JULIAN                     [14]
```

The specific equation for red pine foliage on a Redby soil after combining relevant terms (table 3, page 15),

```
LEAVES=0.0008695*DBH^3.122               [15]
```

does not contain the HEIGHT and JULIAN terms. However, substituting the red pine height estimator

```
HEIGHT=2.921*DBH^0.5213*1.117            [16]
```

into [14], assuming a Julian day of 200 (July 19), and again combining terms, gives a comparable equation,

```
LEAVES=0.001318*DBH^2.990                [17]
```

The leaf estimates for trees 5, 25, and 45 cm d.b.h. are 0.162, 19.9, and 116 kg using the generic equation [17], and 0.132, 20.1, and 126 kg using the specific equation [15]. Of course, the specific equation is preferred in this case because it was developed from an adequate data base and is not influenced in any way by other species. The generic equation is preferred when the data base is meager for a species, when cruder estimates are acceptable, or when tree diameters are mostly near the midpoints of our sample. The ultimate generic equation, of course, is derived by using all terms given for the component to yield a simple equation like [15] and [17]. Otherwise, it may be worthwhile to use equations tailored to species, soil, and vegetative treatment. Most users probably will not require the soil terms. However, the soil terms will probably give somewhat more accurate estimates, especially if stand characteristics are near those in our studies.

CONCLUSIONS

These equations show that soil is a marginally useful variable for allometric estimation of biomass. In contrast, specific gravity and Julian day are strong predictor variables, although they raise more questions than they resolve. Nevertheless, these equations provide some guidance on variability expected from site to site, and probably depict at least the direction of allometric change induced by treatment. Certainly one should expect that site treatments that promote sparse forests will produce trees and shrubs having bushy crowns and disproportionate leaf mass, as we found.

Whether site-specific biomass estimators are needed or whether these or some other equations will suffice depends on the user's accuracy requirements. Freedman (1984) shows that generalized equations, even those developed from combined data sets of trees, shrubs, and herbs, can give accurate and precise estimates of at least total biomass. He reasons that the allometric relationships are consistent because plants need a certain amount of strength to cope with drag forces induced by high winds. Indeed, regional equations for some species cannot be significantly improved locally (Crow 1983). Usually, however, species- and site-specific equations perform significantly better than generalized equations, especially for the lesser components of biomass (Buech and Rugg 1989).

Crow and Schlaegel (1988) provide a guide to the sources and use of biomass estimators. Host *et al.* (1989) developed an interactive microcomputer program based on published equations to estimate aboveground whole-tree biomass of common Lake States species. Smith and Brand (1983) reviewed and assembled equations for 98 species of shrubs and herbs. All these are good alternative sources of estimators, the latter especially when caliper is measured at a different stem height.

ACKNOWLEDGMENTS

J. Bondioli, D. Benson, Dr. A. Hallgren, and D. Lauber provided the BF, CL, and HH study sites. Dr. M. Jurgensen and a number of his graduate students assisted with field data collection, vegetation sampling, and sample preparation for the BF site. This work was greatly facilitated by the tireless determination of J. Elioff.

LITERATURE CITED

Alban, D.H. 1985. **Volume comparison of pine, spruce, and aspen growing side by side**. Res. Note NC-327. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 6 p.

Alban, D.H.; Perala, D.A. 1990a. **Ecosystem carbon following aspen harvesting in the upper Great Lakes**. In: Adams, Roy D., ed. Aspen symposium '89 proceedings; 1989 July 25-27; Duluth, MN. Gen. Tech. Rep. NC-140. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 123-131.

Alban, D.H.; Perala, D.A. 1990b. **Impact of aspen timber harvesting on soils**. In: Gessel, S.P.; Lacate, D.S.; Weetman, G.F.; Powers, R.F., eds. Sustained productivity of forest soils: proceedings of the 7th North American forest soils conference; 1988 July 24-28; Vancouver, BC: University of British Columbia: 377-391.

Alban, D.H.; Perala, D.A. 1992. **Carbon storage in Lake States aspen ecosystems**. Canadian Journal of Forest Research. 22: 1107-1110.

Alban, D.H.; Perala, D.A.; Jurgensen, M.F.; Ostry, M.E.; Probst, J.R. 1991. **Aspen ecosystem properties in the upper Great Lakes**. Res. Pap. NC-300. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 47 p.

Baskerville, G.L. 1972. **Use of logarithmic regression in the estimation of plant biomass**. Canadian Journal of Forest Research. 2: 49-53.

Bendtsen, B.A.; James, W.L.; *et al.* 1987 revised. **Mechanical properties of wood**. In: Wood handbook: wood as an engineering material. Agric. Handb. 72. Washington, DC: U.S. Department of Agriculture, Forest Service: 4-1 - 4-44.

Brown, H.P.; Panshin, A.J.; Forsaith, C.C. 1949. **Textbook of wood technology, volume 1**. New York: McGraw-Hill. 652 p.

Buech, R.R.; Rugg, D.J. 1989. **Biomass relations of shrub components and their generality**. Forest Ecology and Management. 26: 257-264.

Crow, T.R. 1983. **Comparing biomass regressions by site and age for red maple**. Canadian Journal of Forest Research. 13: 283-288.

Crow, T.R.; Schlaegel, B.E. 1988. **A guide to using regression equations for estimating tree biomass**. Northern Journal of Applied Forestry. 5: 15-22.

Fraser, D.A. 1959. **Tree growth in relation to soil moisture**. In: Kozlowski, T.T., ed. Tree growth. New York: Ronald Press: 183-204.

Freedman, B. 1984. **The relationship between the aboveground dry weight and diameter for a wide size range of erect land plants**. Canadian Journal of Botany. 62: 2370-2374.

Grier, C.G.; Running, S.W. 1977. **Leaf area of mature northwestern coniferous forests: relation to site water balance**. Ecology. 58: 893-899.

Host, G.E.; Westin, S.C.; Cole, W.G.; Pregitzer, K.S. 1989. **The microcomputer scientific software series 5: the BIOMASS user's guide**. Gen. Tech. Rep. NC-127. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.

Kennedy, E.I. 1965. **Strength and related properties of woods grown in Canada**. Publ. 1104. Ottawa, ON: Canadian Department of Forestry, Rural Development. 51 p.

Miles, T.J. 1979. **Aspen root biomass and nutrient contents**. Plan B paper. St. Paul, MN: College of Forestry, University of Minnesota. 65 p.

Perala, D.A. 1985. **Using glyphosate herbicide in converting aspen to conifers**. Res. Pap. NC-259. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 4 p.

Perala, D.A. 1987. **Effect of soil and vegetation on growth of planted white spruce**. Res. Pap. NC-281. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.

Perala, D.A.; Alban, D.H. 1982. **Biomass, nutrient distribution, and litterfall in *Populus*, *Pinus*, and *Picea* stands on two different soils in Minnesota**. Plant-Soil. 64: 177-192.

Perala, D.A.; Alban, D.H. **Nutrient concentrations of soil and plant components of aspen-dominated ecosystems of the upper Great Lakes**. (in prep).

Perala, D.A.; Alm, A.A. 1989. **Regenerating paper birch in the Lake States with the shelterwood method**. Northern Journal of Applied Forestry. 6: 151-153.

Ruark, G.A.; Bockheim, J.C. 1987. **Biomass, net primary production, and nutrient distribution for an age sequence of *Populus tremuloides* ecosystems**. Canadian Journal of Forest Research. 18: 433-443.

Smith, W.B.; Brand G.J. 1983. **Allometric biomass equations for 98 species of herbs, shrubs, and small trees**. Res. Note NC-299. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.

Verry, E.S. 1969. **Water storage and related physical characteristics of four mineral soils in North Central Minnesota**. Res. Note NC-78. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 4 p.

Weisberg, S. 1985. **Applied linear regression**. 2d ed. New York: John Wiley & Sons. 324 p.

Wenger, K.E., ed. 1984. **Forestry handbook**. 2d ed. New York: John Wiley & Sons. 1,335 p.

Table 1.—*Vegetation and soils of the eight study sites*[a]

Site	Forest type	Age yrs	Site index m @50 yrs	Soil name	Soil taxonomic class
Baltimore Flats	Aspen Northern hardwoods	47	18.1	Ontonagon clay	Glossic Eutroboralf
Cloquet	Aspen Paper birch	60	17.0	Cloquet fine sandy loam	Typic Dystrochrept
Happy Hollow	Aspen Balsam fir	51	20.0	Zimmerman, loamy fine sand	Alfic Udipsamment
	Aspen Balsam fir	48	21.8	Redby, loamy fine sand	Aquic Udipsamment
	Aspen Balsam fir Black spruce	46	17.6	Leafriver loamy fine sand	Histic Humaquept
Pike Bay	Aspen Northern hardwoods	66	24.2	Warba silt loam	Glossic Eutroboralf
Caberfae	Red pine Jack pine White spruce	46 46 46	21.3 19.2 14.3	Kalkaska sand	Typic Haplorthod
International Falls	Aspen Red pine Jack pine White spruce Black spruce	52 30 30 30 30	21.4 22.6 21.6 18.6 13.4	Redby loamy fine sand	Aquic Udipsamment
Marcell	Aspen Northern hardwoods	66	21.6	Graycalm loamy sand	Alfic Udipsamment
White Cloud	Red pine Jack pine White spruce	46 46 46	18.9 18.6 12.2	Grafton sand	Entic Haplorthod

[a]Sites below the dotted line are not part of the main aspen ecosystem study. The conifers on these sites were planted (Alban 1985).

Table 2.—*Stand dimensional summary*

Site	Overstory	Trees/ha	Basal area
			m^2/ha
Baltimore Flats	Aspen	510	12.6
	total	3,192	24.7
Cloquet	Aspen	368	7.6
	total	701	19.0
Happy Hollow:			
Zimmerman	Aspen	525	11.6
	total	1,873	26.9
Redby	Aspen	400	9.8
	total	2,865	32.9
Leafriver	Aspen	409	9.1
	total	2,131	28.1
Pike Bay	Aspen	282	21.6
	total	1,297	38.3
Caberfae	Red pine	2,656	61.5
	Jack pine	1,384	30.3
	White spruce	3,143	46.4
International	Aspen	629	24.1
Falls	Red pine	1,137	36.3
	Red pine	2,063	50.1
	Red pine	2,755	53.0
	Jack pine	2,249	37.2
	White spruce	1,050	14.7
	White spruce	1,198	21.8
	White spruce	3,657	26.6
	Black spruce	1,236	20.2
	Black spruce	2,100	21.4
	Black spruce	3,015	33.5
Marcell	Aspen	484	27.3
	total	1,315	33.0
White Cloud	Red pine	2,726	57.2
	Jack pine	1,164	25.3
	White spruce	2,427	21.4

Table 3.—*Tree equations.*[a] *Note that the root+stump component is estimated generically only.*

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Abies balsamea (L.) Mill.	60	HEIGHT	CONSTANT	1.390	0.001		
			DBH	7.857-1	0.000		
			ZIMMERMAN[c]	1.079	0.104	0.894	0.0254
	59	LEAVES	CONSTANT	3.583-2	0.000		
			DBH	3.120	0.000		
			HEIGHT	-1.099	0.005		
			WARBA	3.709-1	0.000		
			ZIMMERMAN	6.333-1	0.002	0.902	0.1940
	57	LIVE	CONSTANT	2.403-2	0.000		
		LIMBS	DBH	3.501	0.000		
			HEIGHT	-1.200	0.000		
			WARBA	6.713-1	0.005		
			ZIMMERMAN	7.111-1	0.004	0.946	0.1240
	48	DEAD	CONSTANT	1.216-3	0.000		
		LIMBS	DBH	2.305	0.000		
			ONTONAGON	5.984	0.000		
			WARBA	4.868	0.000		
			ZIMMERMAN	6.059	0.000	0.821	0.6070
	60	BOLE	CONSTANT	5.751-3	0.000		
		BARK	DBH	2.082	0.000		
			HEIGHT	3.834-1	0.007		
			ONTONAGON	1.331	0.000		
			WARBA	1.671	0.000		
			ZIMMERMAN	1.331	0.000	0.987	0.0264
	59	BOLE	CONSTANT	2.348-2	0.000		
		WOOD	DBH	1.926	0.000		
			HEIGHT	7.600-1	0.000		
			ONTONAGON	1.073	0.118		
			WARBA	1.140	0.020		
			ZIMMERMAN	1.097	0.066	0.994	0.0136
	60	TOTAL	CONSTANT	7.052-2	0.000		
		TREE	DBH	2.497	0.000	0.986	0.0306

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Acer rubrum L.	44	HEIGHT	CONSTANT	4.183	0.000		
			DBH	4.558-1	0.000		
			WARBA	1.240	0.000	0.887	0.0099
	45	LEAVES	CONSTANT	1.913-2	0.000		
			DBH	1.867	0.000		
			WARBA	4.962-1	0.000	0.820	0.2095
	43	LIVE	CONSTANT	1.072-1	0.000		
		LIMBS	DBH	2.841	0.000		
			HEIGHT	-1.040	0.020	0.925	0.1236
	38	DEAD	CONSTANT	3.380-3	0.000		
		LIMBS	DBH	2.337	0.000	0.747	0.5313
	44	BOLE	CONSTANT	2.102-2	0.000		
		BARK	DBH	2.191	0.000		
			ONTONAGON	1.257	0.020		
			WARBA	1.461	0.000		
			ZIMMERMAN	1.177	0.028	0.975	0.0376
	45	BOLE	CONSTANT	2.347-2	0.000		
		WOOD	DBH	1.888	0.000		
			HEIGHT	9.912-1	0.000		
			ONTONAGON	1.155	0.005	0.993	0.0111
	45	TOTAL	CONSTANT	8.227-2	0.000		
		TREE	DBH	2.094	0.000		
			HEIGHT	4.728-1	0.001	0.991	0.0139
Acer saccharum Marsh.	42	HEIGHT	CONSTANT	3.804	0.000		
			DBH	5.026-1	0.000	0.948	0.0058
	40	LEAVES	CONSTANT	3.702-2	0.000		
			DBH	1.695	0.000		
			WARBA	5.691-1	0.000	0.853	0.1643
	42	LIVE	CONSTANT	1.549-1	0.087		
		LIMBS	DBH	3.287	0.000		
			HEIGHT	-1.504	0.058		
			ONTONAGON	7.278-1	0.023	0.958	0.1312
	29	DEAD	CONSTANT	2.534-3	0.000		
		LIMBS	DBH	2.297	0.000	0.754	0.7441
	42	BOLE	CONSTANT	7.272-3	0.000		
		BARK	DBH	1.782	0.000		
			HEIGHT	9.114-1	0.018		
			WARBA	1.180	0.013	0.986	0.0305
	42	BOLE	CONSTANT	2.953-2	0.000		
		WOOD	DBH	1.826	0.000		
			HEIGHT	1.036	0.000	0.994	0.0134
	42	TOTAL	CONSTANT	6.273-2	0.000		
		TREE	DBH	1.995	0.000		
			HEIGHT	7.354-1	0.004	0.994	0.0133

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Betulaceae	62	HEIGHT	CONSTANT	3.272	0.000		
			DBH	5.438-1	0.000		
			B.ALLEG[d]	8.664-1	0.019		
			WARBA	1.309	0.000		
			GRAYCALM	1.108	0.110	0.834	0.0175
	63	LEAVES	CONSTANT	7.611-2	0.000		
			DBH	2.763	0.000		
			HEIGHT	-1.483	0.001		
			WARBA	6.374-1	0.003	0.872	0.1927
	62	LIVE	CONSTANT	8.248-2	0.000		
		LIMBS	DBH	3.753	0.000		
			HEIGHT	-1.847	0.000		
			B.ALLEG	1.424	0.018	0.935	0.1602
	31	DEAD	CONSTANT	9.194-4	0.000		
		LIMBS	DBH	2.487	0.000		
			GRAYCALM	1.909-1	0.002	0.691	0.5960
	62	BOLE	CONSTANT	2.025-2	0.000		
		BARK	DBH	2.246	0.000		
			WARBA	1.305	0.000		
			ZIMMERMAN	1.196	0.004		
			GRAYCALM	1.271	0.011	0.978	0.0323
	61	BOLE	CONSTANT	2.198-2	0.000		
		WOOD	DBH	1.865	0.000		
			HEIGHT	1.046	0.000	0.996	0.0078
	61	TOTAL	CONSTANT	6.513-2	0.000		
		TREE	DBH	2.193	0.000		
			HEIGHT	4.675-1	0.000	0.994	0.0098
Betula alleghaniensis Britt.	9	HEIGHT	CONSTANT	2.678	0.001		
			DBH	6.682-1	0.000	0.934	0.0086
	9	LEAVES	CONSTANT	6.960-3	0.002		
			DBH	2.003	0.002	0.724	0.3993
	9	LIVE	CONSTANT	1.748-2	0.000		
		LIMBS	DBH	2.550	0.000	0.931	0.1310
	4	DEAD	CONSTANT	use			
		LIMBS	DBH	Betulaceae			
	9	BOLE	CONSTANT	1.445-2	0.000		
		BARK	DBH	2.451	0.008	0.981	0.0326
	9	BOLE	CONSTANT	5.481-2	0.000		
		WOOD	DBH	2.619	0.000	0.991	0.0167
	9	TOTAL	CONSTANT	8.724-2	0.000		
		TREE	DBH	2.587	0.000	0.991	0.0165

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Betula papyrifera Marsh.	51	HEIGHT	CONSTANT	3.432	0.000		
			DBH	5.255-1	0.000		
			WARBA	1.307	0.000		
			GRAYCALM	1.105	0.098	0.838	0.0150
	54	LEAVES	CONSTANT	8.520-2	0.000		
			DBH	2.744	0.000		
			HEIGHT	-1.510	0.001		
			WARBA	6.361-1	0.015	0.883	0.1738
	53	LIVE	CONSTANT	8.908-2	0.000		
		LIMBS	DBH	3.772	0.000		
			HEIGHT	-1.893	0.000	0.938	0.1672
	27	DEAD	CONSTANT	8.746-4	0.000		
		LIMBS	DBH	2.496	0.000		
			GRAYCALM	1.971-1	0.002	0.712	0.6100
	53	BOLE	CONSTANT	2.198-2	0.000		
		BARK	DBH	2.215	0.000		
			WARBA	1.382	0.000		
			ZIMMERMAN	1.199	0.002		
			GRAYCALM	1.265	0.010	0.980	0.0296
	52	BOLE	CONSTANT	2.214-2	0.000		
		WOOD	DBH	1.857	0.000		
			HEIGHT	1.048	0.000	0.996	0.0063
	52	TOTAL	CONSTANT	6.815-2	0.000		
		TREE	DBH	2.194	0.000		
			HEIGHT	4.466-1	0.000	0.995	0.0084
Carpinus caroliniana Walt.	0	ALL	use Betulaceae				
Fraxinus americana L., *F. nigra* Marsh, *F. pensylvanica* Marsh.	17	HEIGHT	CONSTANT	3.433	0.000		
			DBH	5.770-1	0.000		
			ONTONAGON	8.255-1	0.006	0.925	0.0127
	17	LEAVES	CONSTANT	2.606-3	0.000		
			DBH	2.416	0.000		
			ONTONAGON	1.395	0.090	0.947	0.1209
	17	LIVE	CONSTANT	7.106-3	0.000		
		LIMBS	DBH	2.728	0.000	0.933	0.2073
	14	DEAD	CONSTANT	1.675-2	0.014		
		LIMBS	DBH	2.007	0.019	0.328	2.5578
	17	BOLE	CONSTANT	1.219-2	0.000		
		BARK	DBH	1.719	0.000		
			HEIGHT	6.607-1	0.022	0.989	0.0203
	17	BOLE	CONSTANT	1.424-2	0.000		
		WOOD	DBH	1.512	0.000		
			HEIGHT	1.518	0.000	0.998	0.0060
	18	TOTAL	CONSTANT	1.850-2	0.000		
		TREE	DBH	1.329	0.001		
			HEIGHT	1.766	0.002	0.963	0.0841

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Ostrya virginiana (Mill.) K.Koch	13	HEIGHT	CONSTANT	4.932	0.000		
			DBH	4.183-1	0.000		
			ONTONAGON	7.775-1	0.008	0.773	0.0160
	13	LEAVES	CONSTANT	1.306-2	0.000		
			DBH	1.843	0.001	0.630	0.4361
	13	LIVE	CONSTANT	7.989-3	0.000		
		LIMBS	DBH	2.665	0.000		
			ONTONAGON	1.502	0.080	0.931	0.1206
	10	DEAD	CONSTANT	2.861-3	0.001		
		LIMBS	DBH	2.485	0.001	0.712	0.5483
	13	BOLE	CONSTANT	7.638-3	0.000		
		BARK	DBH	1.588	0.000		
			HEIGHT	8.045-1	0.003	0.984	0.0143
	12	BOLE	CONSTANT	3.327-2	0.000		
		WOOD	DBH	2.154	0.000		
			HEIGHT	6.559-1	0.001	0.996	0.0056
	12	TOTAL	CONSTANT	6.506-2	0.000		
		TREE	DBH	2.269	0.000		
			HEIGHT	3.964-1	0.093	0.991	0.0133
Picea glauca (Moench) Voss	72	HEIGHT	CONSTANT	2.385	0.000		
			DBH	6.151-1	0.000		
			REDBY	6.825-1	0.000	0.890	0.0160
	73	LEAVES	CONSTANT	3.064-2	0.000		
			DBH	2.787	0.000		
			HEIGHT	-7.147-1	0.006		
			KALKASKA	6.763-1	0.013	0.917	0.1391
	73	LIVE	CONSTANT	7.316-2	0.000		
		LIMBS	DBH	3.530	0.000		
			HEIGHT	-1.784	0.000		
			REDBY	6.615-1	0.019		
			KALKASKA	6.737-1	0.023	0.924	0.1387
	72	DEAD	CONSTANT	3.095-2	0.000		
		LIMBS	DBH	1.002	0.001		
			HEIGHT	1.103	0.020		
			REDBY	6.338-1	0.056		
			KALKASKA	1.508	0.082	0.798	0..2597
	73	BOLE	CONSTANT	1.014-2	0.000		
		BARK	DBH	1.509	0.000		
			HEIGHT	7.830-1	0.000		
			REDBY	1.177	0.008	0.981	0.0207
	72	BOLE	CONSTANT	3.123-2	0.000		
		WOOD	DBH	1.783	0.000		
			HEIGHT	9.260-1	0.000		
			REDBY	8.345-1	0.000	0.993	0.0094
	73	TOTAL	CONSTANT	1.643-1	0.000		
		TREE	DBH	2.248	0.000		
			REDBY	8.128-1	0.000	0.985	0.0210

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Picea mariana (Mill.) B.S.P.	68	HEIGHT	CONSTANT	2.190	0.000		
			DBH	5.337-1	0.000		
			ZIMMERMAN	1.342	0.000	0.865	0.0146
	68	LEAVES	CONSTANT	1.790-2	0.000		
			DBH	2.383	0.000		
			ZIMMERMAN	4.910-1	0.000	0.926	0.1145
	67	LIVE	CONSTANT	2.478-2	0.000		
		LIMBS	DBH	3.677	0.000		
			HEIGHT	-1.680	0.020		
			ZIMMERMAN	1.548	0.005	0.926	0.1393
	67	DEAD	CONSTANT	1.533-2	0.000		
		LIMBS	DBH	2.074	0.000	0.828	0..2153
	68	BOLE	CONSTANT	1.172-2	0.000		
		BARK	DBH	1.718	0.000		
			HEIGHT	5.906-1	0.000	0.981	0.0197
	68	BOLE	CONSTANT	2.265-2	0.000		
		WOOD	DBH	1.750	0.000		
			HEIGHT	1.073	0.000	0.991	0.0124
	68	TOTAL	CONSTANT	1.137-1	0.000		
		TREE	DBH	2.316	0.000		
			ZIMMERMAN	1.105	0.013	0.983	0.0220
Pinus banksiana Lamb.	40	HEIGHT	CONSTANT	6.117	0.000		
			DBH	3.579-1	0.000		
			REDBY	8.933-1	0.002		
			KALKASKA	9.483-1	0.220	0.846	0.0063
	40	LEAVES	CONSTANT	8.988-4	0.000		
			DBH	2.903	0.000		
			REDBY	1.538	0.045		
			KALKASKA	1.569	0.104	0.820	0.2606
	39	LIVE	CONSTANT	2.956-3	0.000		
		LIMBS	DBH	2.830	0.000	0.942	0.0835
	40	DEAD	CONSTANT	2.391-1	0.207		
		LIMBS	DBH	2.943	0.000		
			HEIGHT	-1.769	0.018		
			GRAFTON	3.556-1	0.000	0.857	0.1806
	41	BOLE	CONSTANT	1.570-2	0.000		
		BARK	DBH	1.775	0.000		
			HEIGHT	3.952-1	0.067		
			REDBY	1.165	0.006		
			KALKASKA	1.294	0.000	0.977	0.0145
	41	BOLE	CONSTANT	1.395-2	0.000		
		WOOD	DBH	1.709	0.000		
			HEIGHT	1.327	0.000	0.988	0.0114
	41	TOTAL	CONSTANT	3.837-2	0.000		
		TREE	DBH	1.950	0.000		
			HEIGHT	8.369-1	0.000	0.988	0.0118

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Pinus resinosa Ait.	68	HEIGHT	CONSTANT	2.921	0.000		
			DBH	5.213-1	0.000		
			REDBY	1.117	0.005		
			KALKASKA	1.449	0.000		
			GRAFTON	1.244	0.000	0.860	0.0107
	69	LEAVES	CONSTANT	6.622-4	0.000		
			DBH	3.122	0.000		
			REDBY	1.313	0.086	0.892	0.3059
	67	LIVE	CONSTANT	3.118-2	0.000		
		LIMBS	DBH	4.098	0.000		
			HEIGHT	-2.271	0.000		
			REDBY	6.497-1	0.000	0.959	0.1102
	69	DEAD	CONSTANT	5.819-4	0.000		
		LIMBS	DBH	2.714	0.000		
			REDBY	4.199	0.000	0.882	0..2341
	69	BOLE	CONSTANT	1.408-2	0.000		
		BARK	DBH	2.090	0.000		
			KALKASKA	1.285	0.000	0.990	0.0123
	69	BOLE	CONSTANT	2.137-2	0.000		
		WOOD	DBH	1.809	0.000		
			HEIGHT	1.037	0.000		
			REDBY	8.823-1	0.000	0.996	0.0060
	69	TOTAL	CONSTANT	4.163-2	0.000		
		TREE	DBH	2.113	0.000		
			HEIGHT	5.833-1	0.000		
			REDBY	9.132-1	0.000	0.996	0.0067
Pinus strobus L.	12	HEIGHT	CONSTANT	3.036	0.000		
			DBH	3.749-1	0.000		
			ZIMMERMAN	1.176	0.084		
			KALKASKA	1.790	0.000	0.934	0.0100
	12	LEAVES	CONSTANT	3.930-2	0.000		
			DBH	1.817	0.000		
			KALKASKA	5.031-1	0.004	0.878	0.0684
	12	LIVE	CONSTANT	1.234-1	0.001		
		LIMBS	DBH	3.744	0.000		
			HEIGHT	-2.435	0.020	0.959	0.0490
	12	DEAD	CONSTANT	2.333-4	0.000		
		LIMBS	DBH	2.984	0.000		
			ZIMMERMAN	4.191	0.015		
			KALKASKA	4.498	0.018	0.908	0.3151
	12	BOLE	CONSTANT	7.889-3	0.000		
		BARK	DBH	2.208	0.000		
			ZIMMERMAN	1.637	0.005		
			KALKASKA	1.975	0.001	0.983	0.0240
	12	BOLE	CONSTANT	1.051-2	0.000		
		WOOD	DBH	1.847	0.000		
			HEIGHT	1.191	0.000	0.992	0.0115
	12	TOTAL	CONSTANT	5.563-2	0.000		
		TREE	DBH	2.284	0.000		
			HEIGHT	2.648-1	0.084	0.991	0.0110

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Salicaceae	182	HEIGHT	CONSTANT	2.218	0.000		
			DBH	5.335-1	0.000		
			WARBA	1.235	0.000		
			GRAYCALM	1.254	0.000		
			JULIAN[e]	1.002	0.000	0.906	0.0154
	167	LEAVES	CONSTANT	2.894-2	0.000		
			DBH	2.837	0.000		
			HEIGHT	-1.448	0.000		
			ONTONAGON	6.220-1	0.002		
			ZIMMERMAN	1.459	0.004		
			P.BALSAM[f]	1.901	0.041	0.784	0.3491
	180	LIVE	CONSTANT	7.820-2	0.000		
		LIMBS	DBH	3.924	0.000		
			HEIGHT	-2.174	0.000		
			ONTONAGON	8.030-1	0.030		
			P.GRAND[g]	8.283-1	0.004		
			P.BALSAM	1.369	0.122	0.943	0.1519
	171	DEAD	CONSTANT	4.718-3	0.000		
		LIMBS	DBH	3.202	0.000		
			HEIGHT	-1.053	0.002		
			ZIMMERMAN	1.291	0.077		
			GRAYCALM	6.579-1	0.001	0.842	0.4436
	181	BOLE	CONSTANT	6.754-3	0.000		
		BARK	DBH	1.796	0.000		
			HEIGHT	1.007	0.000		
			ONTONAGON	9.177-1	0.026		
			WARBA	9.150-1	0.012		
			GRAYCALM	8.388-1	0.000		
			P.BALSAM	8.508-1	0.038	0.990	0.0223
	181	BOLE	CONSTANT	1.569-2	0.000		
		WOOD	DBH	2.017	0.000		
			HEIGHT	9.538-1	0.000		
			ONTONAGON	1.043	0.091		
			GRAYCALM	9.508-1	0.004		
			P.BALSAM	8.612-1	0.003		
			P.GRAND	9.178-1	0.000	0.996	0.0091
	180	TOTAL	CONSTANT	3.824-2	0.000		
		TREE	DBH	2.190	0.000		
			HEIGHT	5.987-1	0.000		
			ZIMMERMAN	1.045	0.036		
			GRAYCALM	9.451-1	0.002		
			P.BALSAM	9.443-1	0.260		
			P.GRAND	9.318-1	0.000	0..996	0.0093
Populus balsamifera L.	4	ALL	use Salicaceae				

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Populus grandidentata Michx.	58	HEIGHT	CONSTANT	3.450	0.000		
			DBH	5.412-1	0.000		
			WARBA	1.238	0.000		
			GRAYCALM	1.221	0.000	0.900	0.0172
	57	LEAVES	CONSTANT	2.740-3	0.000		
			DBH	2.275	0.000		
			WARBA	5.162-1	0.000		
			ZIMMERMAN	1.667	0.011		
			GRAYCALM	6.116-1	0.018	0.847	0.2367
	58	LIVE	CONSTANT	5.646-2	0.000		
		LIMBS	DBH	3.897	0.000		
			HEIGHT	-2.105	0.000	0.952	0.1217
	53	DEAD	CONSTANT	3.520-2	0.000		
		LIMBS	DBH	3.297	0.000		
			HEIGHT	-1.821	0.001		
			GRAYCALM	6.535-1	0.065	0.791	0.3473
	56	BOLE	CONSTANT	1.322-2	0.000		
		BARK	DBH	1.811	0.000		
			HEIGHT	7.450-1	0.000		
			ZIMMERMAN	9.264-1	0.089	0.994	0.0111
	58	BOLE	CONSTANT	1.362-2	0.000		
		WOOD	DBH	2.063	0.000		
			HEIGHT	9.217-1	0.000	0.997	0.0075
	57	TOTAL	CONSTANT	4.072-2	0.000		
		TREE	DBH	2.211	0.000		
			HEIGHT	5.304-1	0.000	0.997	0.0059

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Populus tremuloides Michx.	120	HEIGHT	CONSTANT	2.391	0.000		
			DBH	5.296-1	0.000		
			WARBA	1.278	0.000		
			ZIMMERMAN	1.080	0.021		
			GRAYCALM	1.230	0.000		
			REDBY	1.139	0.007		
			JULIAN	1.002	0.000	0.908	0.0140
	102	LEAVES	CONSTANT	4.629	0.190		
			DBH	2.875	0.000		
			HEIGHT	-1.603	0.000		
			ONTONAGON	4.173-1	0.000		
			ZIMMERMAN	1.221	0.165		
			GRAYCALM	5.551-1	0.006		
			REDBY	2.152	0.002		
			JULIAN	9.798-1	0.000	0.845	0.2481
	115	LIVE LIMBS	CONSTANT	6.059-2	0.000		
			DBH	3.806	0.000		
			HEIGHT	-2.033	0.000		
			WARBA	1.480	0.000		
			ZIMMERMAN	1.347	0.002		
			GRAYCALM	1.241	0.008	0.957	0.1150
	114	DEAD LIMBS	CONSTANT	1.631-3	0.000		
			DBH	3.330	0.000		
			HEIGHT	-1.552	0.003		
			ONTONAGON	1.841	0.007		
			WARBA	2.164	0.002		
			ZIMMERMAN	1.678	0.011		
			GRAYCALM	1.815	0.050		
			JULIAN	1.008	0.003	0.863	0.4340
	120	BOLE BARK	CONSTANT	5.244-3	0.000		
			DBH	1.855	0.000		
			HEIGHT	8.777-1	0.000		
			ZIMMERMAN	1.085	0.031		
			JULIAN	1.002	0.000	0.990	0.0218
	119	BOLE WOOD	CONSTANT	1.516-2	0.000		
			DBH	2.053	0.000		
			HEIGHT	8.777-1	0.000		
			ONTONAGON	1.040	0.101		
			JULIAN	1.001	0.000	0.997	0.0082
	118	TOTAL TREE	CONSTANT	3.590-2	0.000		
			DBH	2.275	0.000		
			HEIGHT	4.407-1	0.000		
			WARBA	1.065	0.046		
			ZIMMERMAN	1.078	0.004		
			GRAYCALM	1.062	0.118		
			JULIAN	1.001	0.002	0.996	0.0089

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Prunus serotina Ehrh., *P. pensylvanica* L. f.	0	ALL	use Generic				
Quercus macrocarpa Michx.	9	HEIGHT	CONSTANT	2.507	0.001		
			DBH	5.569-1	0.000	0.893	0.0104
	9	LEAVES	CONSTANT	3.129-1	0.210		
			DBH	6.681-1	0.116	0.218	0.3123
	9	LIVE	CONSTANT	1.613-2	0.002		
		LIMBS	DBH	2.530	0.000	0.873	0.2569
	9	DEAD	CONSTANT	5.101-3	0.002		
		LIMBS	DBH	2.351	0.002	0.752	0.4937
	9	BOLE	CONSTANT	3.029-2	0.000		
		BARK	DBH	2.064	0.000	0.991	0.0105
	9	BOLE	CONSTANT	6.359-2	0.000		
		WOOD	DBH	2.398	0.000	0.970	0.0498
	9	TOTAL	CONSTANT	1.447-1	0.000		
		TREE	DBH	2.282	0.000	0.972	0.0422
Quercus rubra L.	16	HEIGHT	CONSTANT	3.706	0.000		
			DBH	4.932-1	0.000		
			WARBA	1.181	0.000	0.975	0.0031
	16	LEAVES	CONSTANT	4.801-2	0.000		
			DBH	1.455	0.000	0.811	0.1816
	16	LIVE	CONSTANT	1.684-2	0.000		
		LIMBS	DBH	2.514	0.000	0.907	0.2400
	14	DEAD	CONSTANT	4.780-4	0.000		
		LIMBS	DBH	3.125	0.000	0.808	0.6614
	15	BOLE	CONSTANT	4.408-3	0.000		
		BARK	DBH	2.047	0.000		
			HEIGHT	8.264-1	0.016	0.996	0.0095
	16	BOLE	CONSTANT	2.635-2	0.000		
		WOOD	DBH	1.880	0.000		
			HEIGHT	9.790-1	0.002	0.997	0.0075
	16	TOTAL	CONSTANT	1.335-1	0.000		
		TREE	DBH	2.422	0.000	0.992	0.0180
Salix bebbiana Sarg.	0	ALL	use Generic				

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Thuja occidentalis L.	20	HEIGHT	CONSTANT	1.810	0.001		
			DBH	5.847-1	0.000	0.841	0.0183
	20	LEAVES	CONSTANT	1.001-2	0.000		
			DBH	2.303	0.000	0.881	0.2024
	20	LIVE	CONSTANT	6.964-3	0.000		
		LIMBS	DBH	2.599	0.000	0.910	0.1903
	19	DEAD	CONSTANT	3.812-2	0.017		
		LIMBS	DBH	1.472	0.015	0.259	1.2468
	20	BOLE	CONSTANT	9.025-3	0.000		
		BARK	DBH	1.896	0.000		
			HEIGHT	3.900-1	0.004	0.997	0.0044
	20	BOLE	CONSTANT	4.475-2	0.000		
		WOOD	DBH	1.851	0.000		
			HEIGHT	5.099-1	0.030	0.989	0.0153
	20	TOTAL	CONSTANT	9.101-2	0.000		
		TREE	DBH	2.234	0.000	0.989	0.0157
Tilia americana L.	30	HEIGHT	CONSTANT	4.900	0.000		
			DBH	3.938-1	0.000		
			ONTONAGON	8.570-1	0.006		
			WARBA	1.161	0.016	0.916	0.0097
	30	LEAVES	CONSTANT	4.884-3	0.000		
			DBH	2.094	0.000	0.865	0.2613
	29	LIVE	CONSTANT	6.589-3	0.000		
		LIMBS	DBH	2.677	0.000		
			ONTONAGON	7.570-1	0.091	0.953	0.1515
	16	DEAD	CONSTANT	1.889-1	0.115		
		LIMBS	DBH	3.629	0.000		
			HEIGHT	-3.493	0.002	0.747	0.3908
	31	BOLE	CONSTANT	5.150-3	0.000		
		BARK	DBH	1.507	0.000		
			HEIGHT	1.338	0.000	0.988	0.0240
	31	BOLE	CONSTANT	7.846-3	0.000		
		WOOD	DBH	1.944	0.000		
			HEIGHT	1.164	0.000	0.995	0.0121
	31	TOTAL	CONSTANT	2.322-2	0.000		
		TREE	DBH	2.026	0.000		
			HEIGHT	8.327-1	0.000		
			WARBA	1.131	0.019	0.995	0.0127

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Ulmus americana L.	14	HEIGHT	CONSTANT	2.668	0.000		
			DBH	6.341-1	0.000		
			ONTONAGON	8.935-1	0.183	0.898	0.0169
	14	LEAVES	CONSTANT	6.197-3	0.000		
			DBH	1.935	0.000		
			ONTONAGON	1.640	0.006	0.956	0.0553
	14	LIVE	CONSTANT	5.150-3	0.000		
		LIMBS	DBH	2.635	0.000		
			ONTONAGON	1.836	0.052	0.915	0.2081
	13	DEAD	CONSTANT	2.859-2	0.013		
		LIMBS	DBH	1.553	0.013	0.396	0.9869
	14	BOLE	CONSTANT	1.728-2	0.000		
		BARK	DBH	2.232	0.000	0.989	0.0191
	14	BOLE	CONSTANT	2.232-2	0.000		
		WOOD	DBH	1.928	0.000		
			HEIGHT	9.157-1	0.006	0.993	0.0160
	14	TOTAL	CONSTANT	8.248-2	0.000		
		TREE	DBH	2.468	0.000	0.990	0.0220
Generic[h]	773	HEIGHT	CONSTANT	2.313	0.000		
			DBH	5.620-1	0.000		
			JULIAN	1.001	0.000		
			CONIFER	5.790-1	0.000		
			PINUS	1.718	0.000		
			P.RESINOSA	9.236-1	0.004		
			P.STROBUS	7.132-1	0.000		
			PICEA	1.132	0.002		
			P.MARIANA	1.136	0.000		
			A.BALSAMEA	1.329	0.000		
			P.GRANDIDEN	1.055	0.008		
			Q.MACROCARP	7.421-1	0.000		
			T.AMERICANA	8.811-1	0.000		
			U.AMERICANA	8.968-1	0.005		
			ONTONAGON	1.042	0.044		
			WARBA	1.175	0.000		
			ZIMMERMAN	1.078	0.000		
			GRAYCALM	1.199	0.000		
			KALKASKA	1.298	0.000		
			GRAFTON	1.192	0.000	0.906	0.0190

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
	745	LEAVES	CONSTANT	2.979-2	0.000		
			DBH	2.582	0.000		
			HEIGHT	-9.130-1	0.000		
			JULIAN	9.969-1	0.000		
			JUL*CONIFER	1.004	0.000		
			PICEA	1.877	0.000		
			A.BALSAMEA	2.140	0.000		
			P.RESINOSA	8.923-2	0.000		
			P.RESIN*DBH	8.835-1	0.000		
			ACER SP.	2.353	0.000		
			BETULACEAE	1.793	0.000		
			QUERCUS SP.	1.938	0.000		
			FRAXINUS SP	1.739	0.000		
			P.BALSAMIFE	1.726	0.028		
			WARBA	7.088-1	0.000		
			REDBY	1.195	0.005	0.875	0.2365
	767	LIVE	CONSTANT	4.189-2	0.000		
		LIMBS	DBH	3.540	0.000		
			HEIGHT	-1.580	0.000		
			CONIFER	7.658-1	0.000		
			A.BALSAMEA	1.405	0.000		
			P.RESINOSA	2.062-1	0.000		
			P.RESIN*DBH	3.556-1	0.001		
			T.OCCIDENTA	5.198-1	0.000		
			ACER	1.803	0.000		
			A.SACCHARUM	1.202	0.041		
			BETULACEAE	1.678	0.000		
			B.ALLEGHANI	1.422	0.018		
			FRAXINUS	1.324	0.010		
			P.BALSAMIFE	1.427	0.096		
			P.GRANDIDEN	8.550-1	0.018		
			QUERCUS	1.777	0.000		
			Q.MACROCARP	6.368-1	0.011		
			T.AMERICANA	7.791-1	0.004		
			GRAFTON	1.256	0.022	0.930	0.1758
	676	DEAD	CONSTANT	9.592-3	0.000		
		LIMBS	DBH	2.224	0.000		
			JULIAN	1.005	0.000		
			PICEA	3.172	0.000		
			PINUS	1.471	0.003		
			P.BANKSIANA	2.210	0.000		
			A.SACCHARUM	5.003-1	0.000		
			BETULACEAE	3.542-1	0.000		
			O.VIRGINANA	2.829	0.000		
			QUERCUS	1.631	0.004		
			T.AMERICANA	2.568-1	0.000		
			KALKASKA	2.066	0.000		
			ONTONAGON	2.185	0.000		
			REDBY	1.675	0.000		
			GRAYCALM	1.337	0.066		
			ZIMMERMAN	1.860	0.000		
			WARBA	1.508	0.000	0.756	0.6033

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
	771	BOLE	CONSTANT	3.156-2	0.000		
		BARK	DBH	1.846	0.000		
			HEIGHT	6.660-1	0.000		
			SPECGRAV	1.210	0.000		
			JULIAN	1.002	0.000		
			JUL*CONIFER	9.971-1	0.000		
			PICEA	8.395-1	0.000		
			PINUS	7.671-1	0.000		
			P.STROBUS	1.147	0.028		
			P.RESIN*DBH	-1.320-1	0.000		
			ACER	4.804-1	0.000		
			BETULACEAE	5.368-1	0.000		
			B.ALLEGHANI	7.825-1	0.000		
			O.VIRGINIAN	3.809-1	0.000		
			FRAXINUS	4.045-1	0.000		
			P.BALSAMIFE	7.775-1	0.003		
			QUERCUS	4.878-1	0.000		
			Q.MACROCARP	8.726-1	0.060		
			T.AMERICANA	9.208-1	0.022		
			U.AMERICANA	4.150-1	0.000		
			GRAYCALM	1.069	0.023		
			KALKASKA	1.083	0.049		
			LEAFRIVER	1.116	0.005		
			REDBY	1.071	0.004		
			WARBA	1.119	0.000		
			ZIMMERMAN	1.048	0.074	0.987	0.0276
	770	BOLE	CONSTANT	2.869-2	0.000		
		WOOD	DBH	1.886	0.000		
			HEIGHT	9.768-1	0.000		
			SPECGRAV	4.562-1	0.000		
			JULIAN	1.001	0.000		
			JUL*CONIFER	9.990-1	0.000		
			PICEA	1.113	0.000		
			PINUS	1.183	0.000		
			P.RESINOSA	8.403-1	0.000		
			P.STROBUS	7.520-1	0.000		
			A.SACCHARUM	1.117	0.000		
			FRAXINUS	9.275-1	0.013		
			P.BALSAMIFE	7.649-1	0.000		
			P.GRANDIDEN	9.067-1	0.000		
			Q.MACROCARP	8.671-1	0.001		
			T.AMERICANA	7.207-1	0.000		
			U.AMERICANA	8.795-1	0.000		
			KALKASKA	1.130	0.000		
			GRAFTON	1.133	0.000	0.994	0.0141

(table 3 continued)

(table 3 continued)

Species[b]	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
	771	TOTAL ABOVE-GROUND	CONSTANT	1.710-1	0.000		
			DBH	2.181	0.000		
			HEIGHT	4.389-1	0.000		
			SPECGRAV	1.150	0.000		
			JULIAN	1.001	0.000		
			JUL*CONIFER	9.991-1	0.000		
			A.BALSAMEA	1.179	0.000		
			PICEA	1.341	0.000		
			P.MARIANA	8.332-1	0.000		
			P.RESINOSA	7.737-1	0.000		
			ACER	7.960-1	0.000		
			BETULACEAE	8.083-1	0.000		
			B.ALLEGHANI	8.895-1	0.018		
			O.VIRGINIAN	7.282-1	0.000		
			FRAXINUS	7.019-1	0.000		
			P.BALSAMIFE	8.078-1	0.002		
			P.GRANDIDEN	9.113-1	0.000		
			QUERCUS	7.148-1	0.000		
			Q.MACROCARP	8.293-1	0.001		
			T.AMERICANA	7.883-1	0.000		
			U.AMERICANA	6.556-1	0.000		
			GRAFTON	1.078	0.020	0.992	0.0172
A11	17	ROOTS +STUMP	CONSTANT	9.178-2	0.014		
			DBH	2.498	0.000		
			HEIGHT	-6.471-1	0.072		
			L.F.S.[i]	7.404-1	0.0087	0.926	0.0268

[a]Equation form is :

Component weight=Constant*D.b.h.^b*Height^c*Soil

where weight=kg, d.b.h.=cm, height=m, b and c are parameters for d.b.h. and height, and soil=soil parameter (multiplier).

[b]See table 5 for distribution of species by soil and table 10 for diameter range.

[c]Zimmerman includes Redby and Leafriver.

[d]*Betula alleghaniensis* multiplier.

[e]Julian day. The form of this multiplier is:

parameter^Julian day

[f]*Populus balsamifera* multiplier.

[g]*Populus grandidentata* multiplier.

[h]Note the many multipliers by species, species groups, and their interactions with other variables. The form of d.b.h. interaction multipliers is:

D.b.h.^parameter.

Specgrav is specific gravity (table 4). Its multiplier is in the form:

Specgrav^parameter.

[i]L.F.S.=unnamed loamy fine sand (Perala and Alban 1982).

Table 4.—*Wood specific gravity (ovendry weight and fresh volume), both published (Brown* et al. *1949, Kennedy 1965, Bendtsen* et al. *1987) and observed in this study, including significant soil differences*

Species	Specific gravity			Soil
	Published	Observed[a]	Other[a]	
Abies balsamea	0.33	0.34	0.36	Ontonagon
Acer rubrum	0.49	0.55	0.62	Ontonagon
Acer saccharum	0.56	0.68	0.71	Ontonagon
Acer spicatum	0.44[b]	na[c]	—	—
Alnus crispa	0.37[b]	na	—	—
Betula alleghaniensis	0.55	0.60	na	—
Betula papyrifera	0.48	0.54	none	—
Carpinus caroliniana	0.58	na	—	—
Fraxinus americana	0.55	0.54	0.61	Ontonagon
F. nigra	0.45	pooled with above		
F. pennsylvanica	0.53	pooled with above		
Ostrya virginiana	0.63	0.66	none	—
Picea glauca	0.33	0.36	none	—
Picea mariana	0.38	0.41	none	—
Pinus banksiana	0.40	0.41	0.44	Cloquet
Pinus resinosa	0.41	0.36	0.38	Cloquet
Pinus strobus	0.34	0.31	none	—
Populus balsamifera	0.37	0.40	na	—
Populus grandidentata	0.36	0.42	none	—
Populus tremuloides	0.35	0.44	none	—
Prunus serotina	0.47	na	—	—
Quercus macrocarpa	0.58	0.65	na	—
Quercus rubra	0.56	0.57	none	—
Salix bebbiana	0.36[b]	na	—	—
Thuja occidentalis	0.29	0.31	na	—
Tilia americana	0.32	0.35	39	Warba
Ulmus americana	0.46	0.54	none	—

[a]"Observed" is mean of observations without data for "other" soils that were significantly different ($p<.05$).

[b]Specific gravity for these species unavailable. Assumed values for *Acer saccharinum*, *Alnus rubra*, and *Salix nigra*, respectively.

[c]Not available.

Table 5.—*Number of trees sampled by species and soil series*

Species	Soil series								Total
	Cloquet	Ontonagon	Warba	Zimmerman	Graycalm	Redby	Kalkaska	Grafton	
A. balsamea	10	24	9	17					60
A. rubrum	10	6	9	15	5				45
A. saccharum		18	20		4				42
B. alleghaniensis			9						9
B. papyrifera	18		11	20	5				54
Fraxinus spp.		7	11						18
O. virginiana		4	9						13
P. glauca						53	10	10	73
P. mariana				21		48			69
P. banksiana	10					21	5	5	41
P. resinosa	11					48	5	5	69
P. strobus	3			4			5		12
P. balsamifera	4								4
P. grandidentata	20		18	10	10				58
P. tremuloides	19	20	21	20	31	9			120
Q. macrocarpa				9					9
Q. rubra	6		10						16
T. occidentalis				20					20
T. americana		16	10		5				31
U. americana		4	10						14
TOTAL	111	99	147	136	60	179	25	20	777

Table 6.—*Sapling equations*[a]. *See table 8 for distribution by soil and age, and table 9 for distribution of species by diameter class*

Species	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Acer rubrum L.	2	STEMS	use Generic				
	2	LEAVES	" "				
Acer spicatum Lam.	1	STEMS	use Generic				
	1	LEAVES	" "				
Alnus crispa (Ait.) Pursh	1	STEMS	use Betulaceae (table 8)				
	1	LEAVES	" "				
Betula alleghaniensis Britt.	0	STEMS	use Betulaceae				
	0	LEAVES	" "				
Betula papyrifera Marsh.	3	STEMS	use Betulaceae				
	3	LEAVES	" "				
Carpinus caroliniana Walt.	0	STEMS	use Betulaceae				
	0	LEAVES	" "				
Fraxinus americana L., *F. nigra* Marsh, *F. pennsylvanica* Marsh.	1	STEMS	use Generic				
	1	LEAVES	" "				
Populus balsamifera L.	4	STEMS	use *Populus* sp. (table 8)				
	5	LEAVES	" " "				
Populus grandidentata Michx.	26	STEMS	CONSTANT	1.857-1	0.005		
			DBH	2.520	0.000	0.917	
			WARBA	1.190+1	0.003	0.923	
			DBH*WARBA	-7.197-1	0.002	0.941	
			SPRUCE[b]	1.284	0.054	0.940	
			FULL[c]	1.234	0.018	0.953	0.0192
	26	LEAVES	CONSTANT	4.705-1	0.354		
			DBH	1.931	0.000	0.531	
			AGE	-3.563-1	0.091	0.573	
			SPRUCE	2.174	0.002	0.682	
			SHELT[d]	1.351	0.087	0.711	0.0826

(table 6 continued)

(table 6 continued)

Species	Cases	Com-ponent	Variable	Para-meter	Prob.	Adj. R^2	Residual mean square
Populus tremuloides Michx.	131	STEMS	CONSTANT	2.484-1	0.000		
			DBH	2.322	0.000	0.932	
			AGE	2.845-1	0.001	0.949	
			WARBA	3.435	0.004	0.949	
			DBH*WARBA	-3.606-1	0.003	0.953	
			SHELT	9.055-1	0.033	0.954	0.0186
	131	LEAVES	CONSTANT	1.061	0.914		
			DBH	2.365	0.000	0.601	
			AGE	-1.518	0.000	0.651	
			WARBA	5.554-1	0.000	0.778	
			SPRUCE	1.399	0.000	0.815	0.0757
Quercus macrocarpa Michx.	1	STEMS	use Generic				
	1	LEAVES	" "				
Quercus rubra L.	0	STEMS	use Generic				
	0	LEAVES	" "				
Tilia americana L.	0	STEMS	use Generic				
	0	LEAVES	" "				
Ulmus americana L.	0	STEMS	use Generic				
	0	LEAVES	" "				
Generic	170	STEMS	CONSTANT	5.380-1	0.023		
			DBH	2.341	0.000	0.917	
			AGE	2.924-1	0.000	0.931	
			SG	8.278-1	0.000	0.938	
			WARBA	5.135	0.000	0.938	
			DBH*WARBA	-4.747-1	0.000	0.945	0.0217
	171	LEAVES	CONSTANT	1.260+1	0.000		
			DBH	2.297	0.000	0.516	
			AGE	-1.394	0.000	0.574	
			SG	2.264	0.000	0.610	
			ONTONAGON	8.526-1	0.008	0.608	
			WARBA	5.487-1	0.000	0.722	
			SPRUCE	1.436	0.000	0.749	0.0961
	50	ROOTS	STEMODW[e]	7.752-1	0.000	0.979	0.2958

[a]Equation form is:

Component weight=Constant*D.b.h.^b*Age^c*Soil and treatment multipliers

where weight=g, d.b.h.=mm, age=years, b and c are parameters for d.b.h. and age.

[b]Spruce = conversion treatment.

[c]Full = full-tree logged.

[d]Shelt = shelterwood treatment.

[e]The form of this equation is simply:

Root ODW=Stem ODW^b.

Table 7.—*Shrub layer equations*[a]. *See table 9 for distribution by soil and age, and table 10 for distribution of species by diameter class*

Species	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Abies balsamea (L.) Mill.	13	STEMS	CONSTANT	8.088-2	0.000		
			D15	2.662	0.000	0.976	0.0868
	13	LEAVES	CONSTANT	1.193-1	0.001		
			D15	2.230	0.000	0.878	0.3341
	0	ROOTS	use Generic				
Acer rubrum L.	49	STEMS	CONSTANT	6.242-2	0.000		
			D15	2.486	0.000	0.955	
			AGE	3.991-1	0.000	0.964	
			ONTONAGON	7.953-1	0.003	0.970	
			OLD[b]	2.499	0.001	0.975	0.0622
	47	LEAVES	CONSTANT	9.901-2	0.001		
			D15	2.113	0.000	0.907	
			ONTONAGON	8.209-1	0.017	0.911	
			SPRUCE	1.621	0.000	0.930	
			FULL	6.778-1	0.000	0.951	0.0714
	2	ROOTS	CONSTANT	2.026-1		see	
			D15	2.187		Generic	
			WARBA	7.162-1			
Acer saccharum Marsh.	51	STEMS	CONSTANT	2.207-2	0.000		
			D15	3.047	0.000	0.960	
			AGE	2.402-1	0.004	0.965	
			OLD	2.773	0.000	0.976	0.0917
	48	LEAVES	CONSTANT	1.688-1	0.000		
			D15	2.134	0.000	0.918	
			AGE	-1.510-1	0.018	0.928	
			ONTONAGON	6.515-1	0.000	0.960	
			SPRUCE	1.159	0.026	0.964	0.0450
	18	ROOTS	CONSTANT	2.098-1		see	
			D15	2.187		Generic	
			WARBA	7.162-1			
Acer spicatum Lam.	12	STEMS	CONSTANT	1.361-1	0.348		
			D15	1.960	0.001	0.950	
			AGE	6.824-1	0.026	0.959	
			SHELT	1.480	0.035	0.976	0.0570
	12	LEAVES	CONSTANT	1.242-1	0.020		
			D15	2.021	0.000	0.947	
			FULL	1.360	0.045	0.965	
			OLD	5.816-1	0.000	0.967	0.0440
	8	ROOTS	CONSTANT	1.290-1		see	
			D15	2.187		Generic	
			WARBA	7.162-1			

(table 7 continued)

(table 7 continued)

Species	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Alnus crispa (Ait.) Pursh	4	STEMS	use Betulaceae (table 8)				
	4	LEAVES	" "				
	1	ROOTS	CONSTANT	1.011-1		see	
			D15	2.187		Generic	
			WARBA	7.162-1			
Amelanchier spp. Medic.	37	STEMS	CONSTANT	1.630-1	0.000		
			D15	2.494	0.000	0.958	0.0901
	35	LEAVES	CONSTANT	1.070-1	0.000		
			D15	1.925	0.000	0.869	
			OLD	3.527-1	0.000	0.919	0.1673
	7	ROOTS	CONSTANT	1.826-1		see	
			D15	2.187		Generic	
			WARBA	7.162-1			
Betula alleghaniensis Britt.	1	STEMS	use Betulaceae (table 8)				
	1	LEAVES	" "				
	0	ROOTS	use Generic				
Betula papyrifera Marsh.	66	STEMS	CONSTANT	2.373-2	0.000		
			D15	2.687	0.000	0.962	
			AGE	4.838-1	0.000	0.972	
			WARBA	1.218	0.032	0.974	0.0846
	66	LEAVES	CONSTANT	6.132-2	0.002		
			D15	2.174	0.000	0.881	
			SPRUCE	1.342	0.042	0.887	0.2545
	0	ROOTS	use Generic				
Carpinus caroliniana Walt.	2	STEMS	use Betulaceae				
	4	LEAVES	" "				
	0	ROOTS	use Generic				
Cornus alternifolia L. f., *C. rugosa* Lam., *C. stolonifera* Michx.	29	STEMS	CONSTANT	4.635-2	0.000		
			D15	3.096	0.000	0.974	
			OLD	7.048-1	0.085	0.976	0.0747
	35	LEAVES	CONSTANT	1.004-1	0.001		
			D15	2.476	0.000	0.794	
			OLD	3.608-1	0.066	0.810	0.5662
	12	ROOTS	CONSTANT	1.084-1		see	
			D15	2.187		Generic	
			WARBA	7.162-1			
Corylus cornuta Marsh.	117	STEMS	CONSTANT	4.544-2	0.000		
			D15	2.848	0.000	0.934	
			AGE	1.594-1	0.003	0.936	
			SPRUCE	7.264-1	0.001	0.941	0.1352
	116	LEAVES	CONSTANT	7.188-2	0.000		
			D15	2.244	0.000	0.800	0.3183
	30	ROOTS	CONSTANT	1.383-1		see	
			D15	2.187		Generic	
			WARBA	7.162-1			

(table 7 continued)

(table 7 continued)

Species	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Diervilla lonicera Mill.	42	STEMS	CONSTANT	1.955-1	0.001		
			D15	1.054	0.002	0.099	
			AGE	2.957-1	0.001	0.390	
			ONTONAGON	1.557-1	0.000	0.588	0.1485
	44	LEAVES	CONSTANT	2.152-1	0.001		
			D15	1.424	0.000	0.294	
			ONTONAGON	1.801-1	0.000	0.482	0.1713
	0	ROOTS	use Generic				
Dirca palustris L.	16	STEMS	CONSTANT	2.426-2	0.000		
			D15	2.736	0.000	0.932	0.0843
	16	LEAVES	CONSTANT	6.979-2	0.000		
			D15	1.735	0.000	0.908	0.0977
	13	ROOTS	CONSTANT	5.603-2		see	
			D15	2.187		Generic	
			WARBA	7.162-1			
Fraxinus americana L., *F. nigra* Marsh, *F. pennsylvanica* Marsh.	22	STEMS	CONSTANT	5.041-2	0.001		
			D15	2.545	0.000	0.952	
			AGE	3.400-1	0.002	0.970	
			OLD	2.784	0.026	0.976	0.0771
	21	LEAVES	CONSTANT	7.334-2	0.000		
			D15	2.088	0.000	0.918	
			OLD	5.993-1	0.047	0.926	0.1312
	6	ROOTS	CONSTANT	1.203-1		see	
			D15	2.187		Generic	
			WARBA	7.162-1			
Ledum groenlandicum Oeder	0	STEMS	use Generic				
	0	LEAVES	" "				
	0	ROOTS	" "				
Lonicera canadensis Bartr.	16	STEMS	CONSTANT	1.150-1	0.000		
			D15	2.749	0.000	0.906	0.1752
	16	LEAVES	CONSTANT	1.176-1	0.000		
			D15	1.891	0.000	0.859	0.1309
	1	ROOTS	CONSTANT	3.532-1		see	
			D15	2.187		Generic	
			WARBA	7.162-1			
Ostrya virginiana (Mill.) K.Koch	22	STEMS	CONSTANT	2.987-2	0.000		
			D15	3.082	0.000	0.966	0.1034
	22	LEAVES	CONSTANT	1.430-1	0.001		
			D15	2.666	0.000	0.807	
			AGE	-1.097	0.000	0.894	
			OLD	8.115-3	0.000	0.925	0.2220
	10	ROOTS	CONSTANT	1.535-1		see	
			D15	2.187		Generic	
			WARBA	7.162-1			

(table 7 continued)

(table 7 continued)

Species	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Picea glauca (Moench.) Voss.	0	STEMS	use *Abies balsamea*				
	0	LEAVES	" " "				
	0	ROOTS	" " "				
Pinus strobus L.	0	STEMS	use *Abies balsamea*				
	0	LEAVES	" " "				
	0	ROOTS	" " "				
Populus balsamifera L.	5	STEMS	use *Populus* (table 8)				
	5	LEAVES	" " "				
	0	ROOTS	use *Populus tremuloides*				
Populus grandidentata Michx.	56	STEMS	CONSTANT	1.671-1	0.012		
			D15	2.329	0.000	0.979	0.0436
	56	LEAVES	CONSTANT	2.266-1	0.207		
			D15	2.068	0.000	0.911	
			AGE	-5.506-1	0.000	0.918	
			WARBA	8.317-1	0.046	0.920	
			SPRUCE	1.798	0.000	0.936	0.0887
	0	ROOTS	use *Populus tremuloides*				
Populus tremuloides Michx.	234	STEMS	CONSTANT	7.789-2	0.000		
			D15	2.563	0.000	0.949	
			AGE	1.107-1	0.008	0.950	
			ONTONAGON	8.453-1	0.000	0.952	
			SHELT	8.849-1	0.040	0.953	0.0817
	231	LEAVES	CONSTANT	8.338-2	0.000		
			D15	2.248	0.000	0.829	
			AGE	-4.375-1	0.000	0.854	
			WARBA	7.487-1	0.001	0.859	
			SPRUCE	1.445	0.000	0.877	
			SHELT	1.235	0.013	0.880	
			OLD	3.305-1	0.000	0.904	0.1571
	11	ROOTS	CONSTANT	9.769-2		see	
			D15	2.187		Generic	
			WARBA	7.162-1			
Prunus serotina Ehrh., *P. pensylvanica* L. f.	7	STEMS	CONSTANT	1.263-1	0.087		
			D15	2.496	0.002	0.942	
			OLD	2.842-1	0.096	0.989	0.0225
	7	LEAVES	CONSTANT	3.475-2	0.000		
			D15	2.512	0.000	0.992	0.0336
	0	ROOTS	use Generic				

(table 7 continued)

(table 7 continued)

Species	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Prunus virginiana L.	23	STEMS	CONSTANT	1.161-1	0.000		
			D15	2.508	0.000	0.932	
			WARBA	1.267	0.024	0.933	
			SPRUCE	7.855-1	0.022	0.947	0.0392
	23	LEAVES	CONSTANT	6.887-2	0.000		
			D15	2.445	0.000	0.787	
			AGE	-3.415-1	0.031	0.834	
			ONTONAGON	5.735-1	0.014	0.849	
			GLY	1.786	0.011	0.890	0.0982
	0	ROOTS	use Generic				
Quercus macrocarpa Michx.	1	STEMS	use Generic				
	1	LEAVES	" "				
	0	ROOTS	" "				
Quercus rubra L.	13	STEMS	CONSTANT	6.487-2	0.000		
			D15	2.836	0.000	0.972	0.0913
	13	LEAVES	CONSTANT	1.018-1	0.000		
			D15	2.152	0.000	0.941	0.1158
	0	ROOTS	use Generic				
Ribes triste Pall.	7	STEMS	use Generic				
	7	LEAVES	" "				
	0	ROOTS	" "				
Salix bebbiana Sarg.	75	STEMS	CONSTANT	4.262-2	0.000		
			D15	2.705	0.000	0.946	
			AGE	2.872-1	0.016	0.947	
			ONTONAGON	6.508-1	0.000	0.958	
			OLD	2.469	0.006	0.962	0.0944
	75	LEAVES	CONSTANT	7.912-2	0.000		
			D15	2.140	0.000	0.849	
			ONTONAGON	6.731-1	0.006	0.860	
			SPRUCE	1.560	0.000	0.874	
			SHELT	1.403	0.018	0.882	0.1904
	1	ROOTS	CONSTANT	9.769-2		see	
			D15	2.187		Generic	
			WARBA	7.162-1			
Tilia americana L.	58	STEMS	CONSTANT	8.896-2	0.000		
			D15	2.449	0.000	0.886	
			ONTONAGON	1.489	0.007	0.898	0.2872
	53	LEAVES	CONSTANT	1.063	0.964		
			D15	1.860	0.000	0.892	
			AGE	-1.168	0.001	0.890	
			OLD	8.412-2	0.001	0.900	
			ONTONAGON	1.452	0.017	0.910	0.1888
	2	ROOTS	CONSTANT	1.047-1		see	
			D15	2.187		Generic	
			WARBA	7.162-1			

(table 7 continued)

(table 7 continued)

Species	Cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Ulmus americana L.	8	STEMS	use Generic				
	8	LEAVES	" "				
	1	ROOTS	CONSTANT	2.098-1		see Generic	
			D15	2.187			
			WARBA	7.162-1			
Viburnum rafinesquianum Schult.	2	STEMS	use Generic				
	2	LEAVES	" "				
	0	ROOTS	" "				
Viburnum trilobum Marsh.	0	STEMS	use Generic				
	0	LEAVES	" "				
	0	ROOTS	" "				
Generic	1542	STEMS	CONSTANT	5.237-2	0.000		
			D15	2.663	0.000	0.910	
			AGE	2.258-1	0.000	0.911	
			ONTONAGON	1.088	0.004	0.911	
			GRAYCALM	1.182	0.026	0.912	
			SPRUCE	9.130-1	0.003	0.913	
			OLD	1.625	0.000	0.916	0.2423
	1569	LEAVES	CONSTANT	1.615-1	0.000		
			D15	1.985	0.000	0.832	
			AGE	-1.682-1	0.000	0.833	
			ONTONAGON	1.168	0.000	0.834	
			GRAYCALM	1.492	0.000	0.835	
			OLD	4.896-1	0.000	0.845	0.3644
	124	ROOTS	CONSTANT	1.318-1	0.000		
			D15	2.187	0.000	0.463	
			SPECIES[c]	1.000	0.000	0.642	
			WARBA	7.162-1	0.012	0.658	0.4620

[a]Equation form is:

Component weight=Constant*D15^b*Age^c*Soil and other multipliers

where weight=g, D15=mm, age=years.

[b]Old = shrubs in mature stands. Use 1 for Age.

[c]Disregard this term in calculations. Given only to show contribution to equation fit.

Table 8.—*Family and genus pooled data equations*

Group	Total cases	Component	Variable	Parameter	Prob.	Adj. R^2	Residual mean square
Betulaceae	68	STEMS: Saplings	CONSTANT	8.161-2	0.000		
			DBH	2.666	0.000		
			AGE	4.243-1	0.000		
		STEMS: Shrubs	CONSTANT	2.980-2	0.000		
			D15	2.666	0.000	0.964	
			AGE	4.243-1	0.000	0.976	0.0763
	67	LEAVES: Saplings	CONSTANT	3.380-1	0.006		
			DBH	2.058	0.000		
			SPRUCE	1.351	0.024		
		LEAVES: Shrubs	CONSTANT	8.227-2	0.006		
			D15	2.058	0.000	0.886	
			SPRUCE	1.351	0.024	0.893	0.2118
Populus sp.	601	STEMS: Saplings	CONSTANT	3.853-1	0.001		
			DBH	2.251	0.000		
			AGE	2.421-1	0.000		
			ONTONAGON	9.405-1	0.021		
			SHELT	8.352-1	0.000		
		STEMS: Shrubs	CONSTANT	4.816-2	0.000		
			D15	2.655	0.000	0.973	
			AGE	2.421-1	0.000	0.976	
			ONTONAGON	9.405-1	0.021	0.976	
			SHELT	8.352-1	0.000	0.977	0.0857
	600	LEAVES: Saplings	CONSTANT	2.239-1	0.000		
			DBH	2.146	0.000		
			AGE	-3.709-1	0.000		
			ONTONAGON	9.200-1	0.028		
			WARBA	7.977-1	0.000		
			SPRUCE	1.186	0.000		
			SHELT	1.117	0.025		
			GLYPHOSATE	1.150	0.016		
		LEAVES: Shrubs	CONSTANT	1.123-1	0.000		
			D15	2.146	0.000	0.906	
			AGE	-3.709-1	0.000	0.917	
			ONTONAGON	9.200-1	0.028	0.917	
			WARBA	7.977-1	0.000	0.921	
			SPRUCE	1.186	0.000	0.926	
			SHELT	1.117	0.025	0.926	
			GLYPHOSATE	1.150	0.016	0.927	0.1480

Table 9.—*Number of shrubs and saplings sampled by age and soil series*

Soil	Age (yrs) 1	2	3	5	7	8	11	Old	Total
				Shrubs					
Cloquet	78	70	40	176	0	59	119	89	631
Ontonagon	40	45	43	88	0	33	71	184	504
Warba	120	71	110	87	111	0	0	129	628
Graycalm	0	0	0	0	0	0	0	69	69
Zimmerman	0	0	0	0	0	0	0	7	7
TOTAL	238	186	193	351	111	92	190	478	1,839
				Saplings					
Cloquet	0	0	0	0	0	39	20	0	59
Ontonagon	0	0	0	0	0	31	20	0	51
Warba	0	0	0	41	20	0	0	0	61
TOTAL	0	0	0	41	20	70	40	0	171

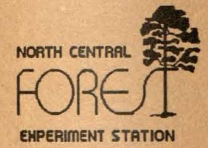
Table 10.—*Diameter range of tree, sapling, and shrub samples*

Species	Trees D.b.h.	Saplings D.b.h.	Shrubs D15
	cm	*mm*	*mm*
Abies balsamea	4-34		3-23
Acer rubrum	4-35	26-28	3-33
Acer saccharum	4-34		3-35
Acer spicatum		33-33	3-25
Alnus crispa		28-28	3-23
Amelanchier spp.			3-27
Betula alleghaniensis	5-21		11
Betula papyrifera	5-32	25-29	3-25
Carpinus caroliniana			3-17
Cornus spp.			3-21
Corylus cornuta			3-25
Diervilla lonicera			3-5
Dirca palustris			3-25
Fraxinus spp.	4-32	25-25	3-33
Lonicera canadensis			3-11
Ostrya virginiana	4-18		3-25
Picea glauca	2-25		
Picea mariana	2-25		
Pinus banksiana	6-39		
Picea resinosa	3-46		
Pinus strobus	5-26		
Populus balsamifera	4-20	27-33	25
Populus grandidentata	3-45	25-65	3-29
Populus tremuloides	3-50	25-78	3-41
Prunus serotina			3-27
Prunus pensylvanica			3-17
Prunus virginiana			3-19
Quercus macrocarpa	6-25		3-3
Quercus rubra	5-34		3-25
Ribes triste			3-7
Salix bebbiana			3-36
Thuja occidentalis	4-31		
Tilia americana	4-47	28-29	3-38
Ulmus americana	4-29		3-31
Viburnum rafinesquianum			5-11

☆U.S. GOVERNMENT PRINTING OFFICE: 1994 - 556-697/80136

Perala, Donald A.; Alban, David H.
1993. **Allometric biomass estimators for aspen-dominated ecosystems in the upper Great Lakes**. Res. Pap. NC-314. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 38 p.

Presents allometric estimators relating aboveground and belowground component weights to diameter measurements of more than 2,500 trees and shrubs encompassing 35 woody species sampled from 8 soil series. The estimators were only weakly related to soil character but were strongly influenced by population density variation induced by silvicultural treatment.

KEY WORDS: *Populus tremuloides*, soil properties, leaves, stems, roots, regression.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.